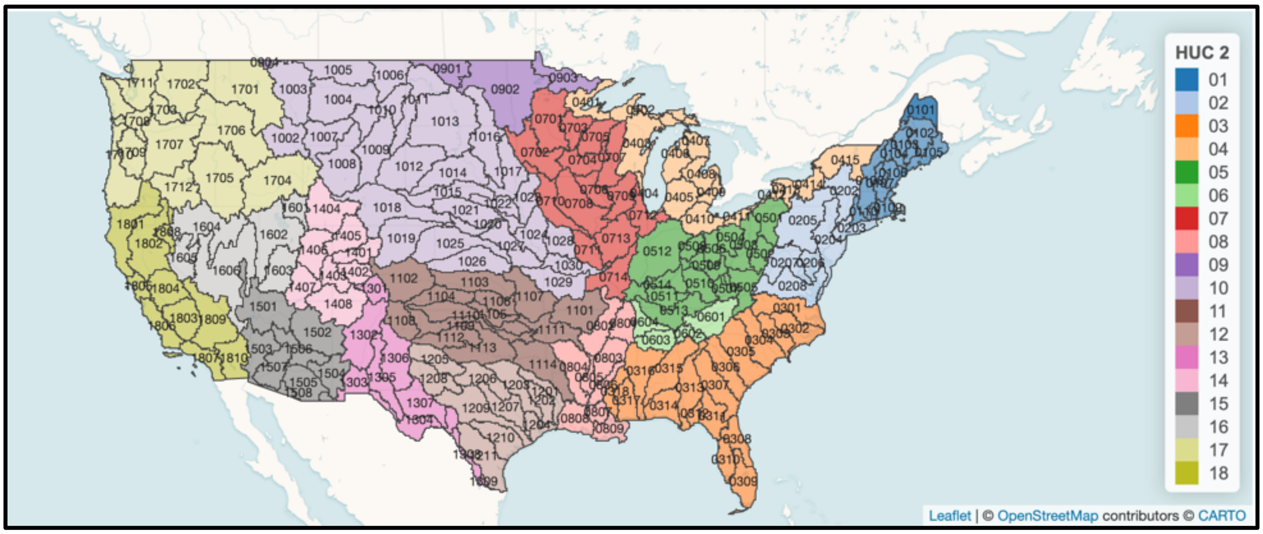
U.S. Army Corps of Engineers (USACE)

Climate Hydrology Assessment Tool (CHAT) User Guide



User Guide

DRAFT, December 2021

U.S. Army Corps of Engineers, Washington, DC
Climate Preparedness and Resilience Community of Practice

Abstract:

Observations in recent decades indicate the climatological baseline and range of climate variability of meteorological conditions are shifting. Climate change is the large-scale shifts in weather patterns, due in part to human-driven activity such as changing land use and increasing carbon dioxide emissions. Changes in future climate conditions pose risks to current and future projects. The shift in weather patterns impacts the resilience of USACE projects and requires additional analysis to inform decisions over the lifetime of the project. USACE developed the Climate Hydrology Assessment Tool (CHAT) to support analysis to determine: 1) changes in baseline climate and hydrologic conditions and 2) any future changes in climate and hydrologic conditions. CHAT supports standardized analysis for efficient applications of ECB 2018-14 by centralizing information appropriate for assessing historical and future conditions. CHAT complements but is not a substitute for professional engineering judgment.

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1. Purpose/Background

Observations in recent decades indicate the climatological baseline and range of climate variability of meteorological conditions are shifting. Climate change is the large-scale shifts in weather patterns, due in part to human-driven activity such as changing land use and increasing carbon dioxide emissions. Changes in future climate conditions pose risks to current and future projects. The shift in weather patterns impacts the resilience of USACE projects and requires additional analysis to inform decisions over the lifetime of the project. USACE developed a basic framework for analysis to identify, communicate, and manage risk in decisions surrounding relevant projects.

The framework is described in Engineering and Construction Bulletin (ECB) 2018-14 which governs applications of climate change information for defining hydrologic impacts to USACE Civil Works projects. The analysis required by ECB 2018-14 focuses on changes in hydroclimatic variables relevant to the problems, opportunities, and alternatives being assessed as part of each USACE study. The guidance requires that changes in both historic and future, projected hydroclimatic conditions be taken into consideration. When analysis is being conducted in support of project design or modification, it is targeted at enabling the project development team (PDT) to incorporate climate change in the Future Without Project condition and the Future With Project condition. USACE's framework for analysis outlines three phases: Phase 1 – Initial Scoping, Phase II – Vulnerability Assessment, and Phase III – Risk Assessment.

USACE developed CHAT to support Phase II, where information is collected and analyzed to determine: 1) changes in the baseline climate and hydrologic conditions and 2) potential future changes in climate and hydrologic conditions which will significantly affect project performance. ECB 2018-14 recommends analysts to assess climate variables over the project lifecycle, which is generally assumed to be 100 years as defined by ER 1110-2-8159 and ER 1105-2-100 unless otherwise specified. USACE policy requires study teams to use hydrologic projections from CMIP5 during the Vulnerability Assessment phase. The CHAT enables users to efficiently analyze historic and future watershed conditions using a standardized and reproducible approach. CHAT supports Phase II activities by providing users with access to CMIP5 based simulations of hydroclimatology incorporating future projections of greenhouse gas emissions. The CHAT provides outputs at the stream-segment level aligned to HUC-8 basins. The purpose of this User Manual is to support the use of Version 2.0 of CHAT released in October 2021. This user guide reviews the data and methodology the tool applies, as well as its user interface. This User Manual is not intended to cover all possible situations one may encounter using the tool. CHAT complements but is not a substitute for professional engineering judgment.

The Climate Hydrology Assessment Tool can be accessed at:
https://climate.sec.usace.army.mil/chat/

2. Technical Background

Data for this tool was processed using the open-source R statistical programming language and the tool was developed using R-Shiny. Users can view the results of hydroclimatic simulations for both a historic period and a future, projected period. In addition to providing for data visualization, the CHAT also presents a series of basic metrics which can be applied to characterize the presented timeseries. Data is available for select stream segments that have been aligned to and are searchable by HUC-8 watershed for the continental United States.

2.1. Data Sources & Methodologies

The CHAT uses output from Global Climate Model (GCM) simulations from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) that have been statistically downscaled and further simulated using a hydrological model to generate daily routed runoff output for a network of stream segments across the entire Continental United States (CONUS). These simulated hydroclimatic outputs are downselected to one representative stream segment per HUC-8 using HUC-8 Geographic Information System (GIS) shapefiles. The following sub-sections describe the data sources and methodologies in more detail. **Error! Reference source not found.Error! Reference source not found.**

2.1.1. GCM

The CHAT displays spatially-downscaled, hydrologically-simulated and statistically-aggregated CMIP5 GCM outputs. Table 1 displays the CMIP5 GCMs whose output were used for this study. CMIP5 GCM outputs are available at daily temporal resolution for calendar years 1950-2099. Baseline historic simulations span the timeframe 1950-2005; these historic simulations assume greenhouse gas emissions to be equivalent to a reconstruction of historically-observed greenhouse gas emission levels. Projected future simulations span the timeframe 2006-2099, which represent projected, climate changed meteorology where various representative concentration pathways (aka "scenarios") (RCP) of greenhouse gas emissions are assumed. CHAT utilizes projected future GCM simulations that were based on accelerated CO2 levels for RCP 4.5 and RCP 8.5. RCP 4.5 represents rising radiative forcing stabilizing at 4.5 W/m2 before 2100, and RCP 8.5 represents rising radiative forcing pathway leading to 8.5 W/m2 in 2100, where radiative forcing expresses the change in energy in the atmosphere due to greenhouse gas emissions. See van Vuren et al. (2011) for more detailed information on the development, assumptions and characteristics of RCPs and guidance on the use of the RCPs.

CMIP5 GCM meteorological data outputs are statistically downscaled to a spatial scale relevant to water resources decision-making using the Localized Constructed Analogs (LOCA) method (Pierce et al., 2014). LOCA-downscaled GCM output and modeled hydrology projections used in this study are available online at: https://gdo-dcp.ucllnl.org/. Additional details about the dataset and spatial downscaling method are documented in Vano et al. (2020), Livneh et al. (2013, 2015) and online at http://loca.ucsd.edu/.

Table 1: Climate models included in projected streamflow data plotted in CHAT

ACCESS1-0	CSIRO-Mk3-6-0	inmcm4
ACCESS1-3	EC-EARTH	IPSL-CM5A-LR
bcc-csm1-1-m	FGOALS-g2	IPSL-CM5A-MR
bcc-csm1-1	GFDL-CM3	MIROC5
CanESM2	GFDL-ESM2G	MIROC-ESM-CHEM
CCSM4	GFDL-ESM2M	MIROC-ESM
CESM1-BGC	GISS-E2-H	MPI-ESM-LR
CESM1-CAM5	GISS-E2-R	MPI-ESM-MR
CMCC-CM	HadGEM2-AO	MRI-CGCM3
CMCC-CMS	HadGEM2-CC	NorESM1-M
CNRM-CM5	HadGEM2-ES	

2.1.2. VIC Model Output

To generate the runoff response presented in the CHAT, downscaled GCM outputs for several meteorological parameters are applied as inputs to the Variable Infiltration Capacity Model (VIC) hydrologic model (VIC; Liang et al, 1996). The VIC hydrological outputs are produced for both the simulated historical timeframe and the projected future timeframe.

The VIC hydrologic model was forced with those LOCA outputs to create a consistent portrayal of unregulated and largely uncalibrated areal hydrology across CONUS. Areal runoff from VIC was routed through the stream network using mizuRoute [Mizukami et al., 2016, doi: 10.5194/gmd-9-2223-2016], resulting in a network of 57,116 stream segments, individually denoted by segment identification (ID) number. These VIC model outputs represent the daily in-channel routed runoff (i.e. streamflow) of each stream segment – valid at the stream segment endpoint (aka “node”) – in units of cubic meters per second. A stream segment typically ends when it is interrupted, for example by joining with another stream segment (i.e. confluence point), the continuation of which is thereafter assigned a new segment ID. Since the runoff is routed, the streamflow value associated with each stream segment is a representation of the cumulative flow including all upstream runoff as well as the local runoff contributions to that specific segment. Those VIC stream segments that corresponded to the terminal end of the river system (e.g. the last leg of a river before either going subsurface or flowing into a large body of water) are referred to as “terminal downstream segments.” Those VIC stream segments that either ended near the outlet of a HUC-8 watershed or flowed directly out of a HUC-8 watershed boundary are referred to as “outlet stream segments.”

A collective subset of terminal downstream segments and outlet stream segments totaling 2,517 segments were identified and cross-walked to each HUC-8 watershed, respectively indicative of cumulative flow within that watershed. In cases where large rivers extend across HUC8 boundaries, the stream segment chosen for a given HUC8 will be representative of cumulative in-channel routed flow from all contributing upstream segments including those in upstream HUC8s where the river flows. Note that VIC-generated terminal downstream segment and outlet stream segment endpoints do not always line up perfectly with HUC-8 borders. Additionally, confluence points just inside the HUC8 boundary can create further ambiguity. Therefore, this crosswalk was performed manually in order to identify the segment(s) that most closely represented the terminal downstream or outlet stream segments within each HUC8 watershed. In most cases, a single terminal downstream segment or outlet stream segment matched up with one of the 2,112 HUC-8 watersheds in CONUS. In the event where there was more than one segment aligned to a single HUC-8, the segment with the largest total flow was chosen. Note that some HUC-8 watersheds did not have a stream segment, or the terminal downstream segment had zero flow, resulting in values of zero for those watersheds; this is usually either because the watershed was very dry (e.g., desert areas) or because the watershed encompassed a body of water (e.g., bay areas or lakes). If a selected HUC-8 has zero flow, then a pop-up message will display to notify the user.

2.1.3. HUC Boundaries

Raw shapefiles for HUC watershed boundaries were obtained from the NHDPlus National Data website (https://www.epa.gov/waterdata/nhdplus-national-data). Shapefiles from the Watershed Boundary Dataset (NHDPlusV21_NationalData_WBDSnapshot_Shapefile_08.7z) were aggregated to the HUC-8 and HUC-4 levels. Boundary geometries were subsampled, reducing the shapefile resolution. Additional information about the dataset can be found in the NHDPlus Version 2: User Guide (McKay et al., 2012).

Watershed boundaries crossing the US-Canada and US-Mexico borders were clipped to only display the areal regions within the United States border. The border file was downloaded from the U.S. Census Cartographic Boundary Files dataset (https://www.census.gov/geographies/mapping-files/time-series/geo/carto-boundary-file.html; cb_2018_us_nation_20m.zip). HUC-4 name assignments were taken from the Watershed Boundary Dataset. HUC-8 name assignments were primarily taken from the Watershed Boundary Dataset. Supplementary HUC-8 name assignments follow USGS Water Resources List (https://water.usgs.gov/GIS/huc_name.html).

2.1.4. Data Processing

The resulting daily HUC-8-aligned routed runoff stream-segment data was converted from cubic meters per second to cubic feet per second and then aggregated into a timeseries of annual-maximum average monthly runoff representing each of the 64 GCM/RCP combinations (i.e., 32 GCMs where each simulation was run twice assuming RCP 4.5 and 8.5 conditions for the future period [2006-2099]) as follows. The HUC-8 level daily, routed runoff was averaged over all days for each month. Then, the annual maximum of those monthly values was calculated across each water year (i.e., defined as Oct. 1 through Sept. 30). For each of the 64 runoff simulations spanning 1950-2099, the inter-model, inter-scenario range statistics (i.e., minimum, maximum and mean) were calculated for those annual-maximum of average-monthly flows. In other words, statistics were calculated across all 64 streamflow simulations. Note that since runoff metrics displayed in CHAT are displayed at annual resolution for each water year, only water years 1951 through 2099 are displayed in CHAT (i.e., because the 1950 water year – Oct 1 1949 to Sep 30 1950 – is incomplete). Further, water year 2006 (Oct 1 2005 – Sep 30 2006) utilizes data from the last part of the historical simulation (Oct 1 2005 – Dec 31 2005) and the first part of the future simulation (Jan 1 2006 – Sep 30 2006). Note that for the historic period (calendar years 1950-2005) the various GCM simulations are conducted with the same reconstruction of historic greenhouse gas emission levels, but the simulations' outputs will still vary due to differences in model configurations (e.g. resolution, parameterizations, representation of climate feedback cycles, etc.). A summary of the data processing steps is shown below.

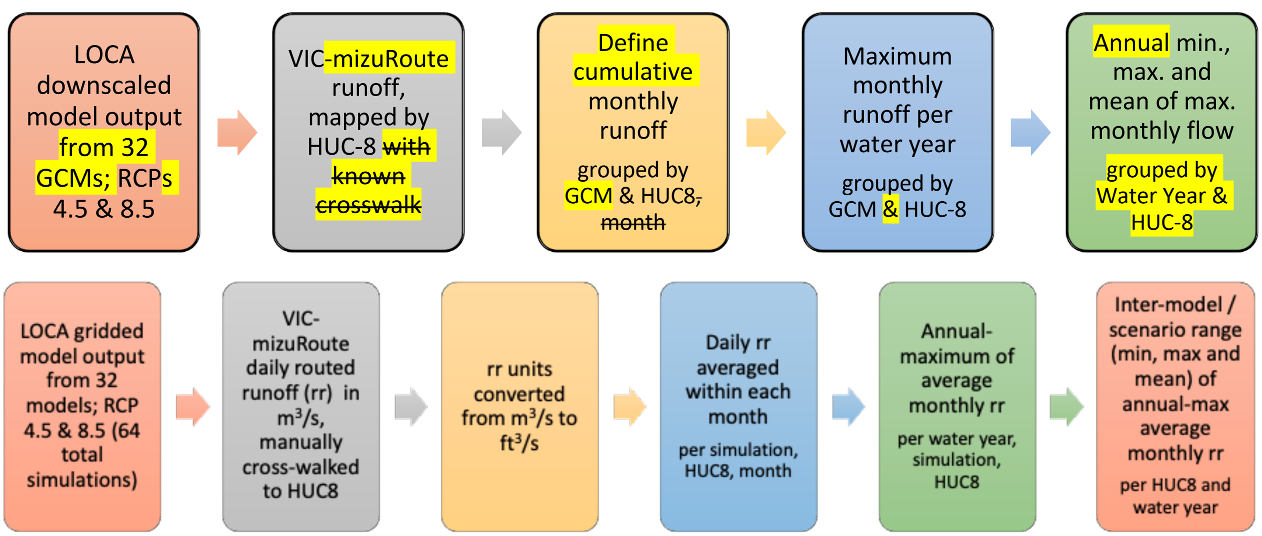


Figure 1: Data processing flow for GCM output.

2.1.5. Trend Analysis

In addition to providing aggregate statistics (i.e., inter-model/scenario minimum, maximum and mean) for annual-maximum average monthly flows, the tool evaluates whether or not there is evidence of a statistically significant trend in the mean of the 64 simulated timeseries for both the historic simulation period (i.e., water years 1951-2005) and the projected future simulation period (i.e., water years 2006-2099). The tool presents a regression line and its associated adjusted R-squared value for each subset of data, as well an evaluation of whether the indicated trendline is statistically significant. The statistical significance of the trendline is evaluated using the student t-test, the Mann-Kendall test and the Spearman Rank-Order test. Various significance (i.e., alpha) thresholds can be selected for individual analysis, depending on several factors in practice, as mentioned in EM 200-1-16. For the t-test, Mann-Kendall test and Spearman Rank-Order test, CHAT uses a default significance level of 0.05, in alignment with ETL 1100-2-3 , indicating that p-values less than or equal to 0.05 will be considered significant. A significance level of 0.05 translates to a 5% probability of encountering a false positive (Type I error): rejecting the null hypothesis given that the null hypothesis is true (e.g., identifying a significant trend when there is actually no significant trend). In other words, setting the significance level at a certain value predetermines the probability of a Type I error. Below is a more detailed description of the metrics used in the tool:

1. **Regression Line**:The slope of each trend can provide the directionality (e.g., increasing or decreasing) of the trend. A negative slope in simulated historical flows can represent reduced streamflow to date, while a negative slope in projected data can represent reduced streamflow due to changes in future climate conditions. Likewise, a positive slope in simulated historical flows can represent increased streamflow to date, while a positive slope in projected data can represent increased streamflow due to climate change. A linear regression equation is fitted to the data using ordinary least squares as described in Chambers (1992) and Wilkinson (1973) to calculate slope.
2. **Adjusted R-Squared**: The R-Squared value represents the percentage of the variance in the observations explained by the model, while also accounting for the number of predictors. An R-squared value of 0 suggests that using the linear model is as effective as using the mean to estimate the trend. A negative R-Squared value suggests that using the displayed linear function is less effective at estimating the trend than using the mean of the observations. The adjusted R-Squared represents how much of the variance in the modeled flow is explained by the model (i.e. the regression line). A low adjusted R-squared suggests that the variability in the data is not closely related to the linearly modeled changes over time. This metric must be considered along with the p-values to draw conclusions. The adjusted R-Squared value is calculated according to Chambers (1992).
3. **t-test p-value**: A measurement that compares the strength of the signal (i.e., sample mean – population mean) to the variation of the data (i.e., the noise of the data). The smaller the magnitude of the p-value, the greater chance of rejecting the null hypothesis (e.g., where the null hypothesis is defined as no trend being present). A large p-value would suggest that it is highly unlikely that a trend exists. For more information, please see Chambers (1992).
4. **Mann-Kendall**: Mann-Kendall is a non-parametric hypothesis test applied to determine the presence of a consistent increasing or decreasing trend. The Mann Kendall trend test uses the Kendall rank correlation of a timeseries to determine if a monotonic trend is present in the dataset. Results presented in CHAT are based on a calculation of the two sided p-value using the methods described in Hipel and McLeod (2005) and Mann (1945).
5. **Spearman Rank Order**: The Spearman Rank-Order Test is another non-parametric measure to determine whether there is an association between the two ranked variables (e.g., time and the measurement of interest). Spearman's rho statistic is used to estimate a rank based measure of association between paired samples and to compute a test of the value being zero. The p-value associated with the Spearman Rank Order test is computed according to the methodology described in Hollander and Wolfe (1973).

2.2. Constraints and Limitations

The CHAT tool relies on modeled meteorological data produced using GCMs and streamflow data generated using the VIC hydrologic model. Assumptions are inherent to any modeling process. Modeling assumptions made constrain how outputs can be used in subsequent analysis. The following constraints to application and interpretation exist for the values presented in the CHAT:

1. Future projections start in 2006 because when CMIP5 was developed, 2006 was defined as the cutoff year where projections rather than a historic reconstitution of greenhouse gas emissions begin to be applied to generate GCM outputs.
2. The trendlines in the ***Modeled Streamflow Trend Analysis*** tab should not be used to predict exact changes in future streamflow. Numerical results should not be directly applied in support of any USACE study/analysis.
3. Simulated, historic climate data and the corresponding streamflow response for water years 1951-2005 should not be treated the same as historical, observed data. Consequently, projected, modeled future data for water years 2006-2099 should not be compared directly to observed data.
4. The VIC model is configured to model the unregulated flow response. The impact of existing hydraulic structures on flow is unaccounted for in the results presented within the CHAT.
5. Even for unregulated watersheds (i.e., those without man-made hydraulic infrastructure) VIC outputs do not precisely reflect observed data. This is due to a number of factors, including the coarse nature of VIC model calibration (described below), limitations and uncertainty inherent in GCMs, GCM assumptions, and GCM downscaling approach.
6. The VIC model is tuned to generate alignment with observations by calibrating several model parameters (e.g. infiltration rate, soil layer depth, etc.), most of which are derived from in situ measurements and/or remote sensing observations. The VIC model has only been coarsely calibrated and calibration quality varies depending on the physical process which dominates runoff response and locale, as well as on the availability and accuracy of meteorological/hydrological observations that were used in calibration. No post-processing of the VIC generated streamflow has been applied to facilitate comparison to observed streamflow data.
7. The data that is shown for each HUC-8 represents in-channel routed runoff for a single VIC stream segment and therefore represents cumulative flow (not local flow) resulting from all upstream segments of that river as well as contributions from local runoff. The data is not a HUC-only or local streamflow value.
8. HUC shapefile data and naming conventions are adopted from the USGS. Due to periodic updates, the availability of shapefiles and naming conventions can change over time.
9. Currently, the tool presents data aggregated annually.

3. CHAT Application

Users can view the inter-model/scenario statistics of simulated, historical and projected, future streamflows for hydrologically-modeled stream segments aligned to each HUC-8 watershed. See the Data Sources and Methodologies section for a detailed description of the data (i.e. where the data comes from and the processes and methodology by which it was produced) and the metrics that are displayed in

CHAT. Please refer to the constraints and limitations section for guidance on interpretation of the information.

The application contains four tabs as shown in Figure 2: 1) Home, 2) Model Projected Streamflow, 3) Model Streamflow Trend and 4) Help.

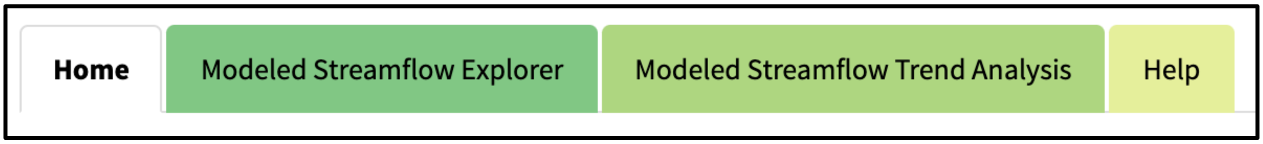


Figure 2: Tabs at the top of the CHAT page

3.1. Home Page Explorer

When the CHAT first loads, users are directed to the ***Home*** tab and are presented with a map of HUC-8s in the continental United States. As indicated previously, HUC watersheds located along the U.S international borders with Mexico and Canada are truncated at the border; this is apparent when watersheds are visualized within the ***Home*** tab. The ***Home*** tab also contains information related to CHAT tool context, application and the latest tool updates.

3.1.1. Overview

The purpose of the ***Home*** this tab is to allow users to visually identify the HUC-8 of interest and how HUC-8 boundaries overlap with HUC-4 and HUC-2 boundaries. Within the ***Home*** Tab, the user can select a HUC-8 for analysis and proceed to subsequent tabs.

3.1.2. Interacting with Home Page Explorer

Two dropdown menus can be applied to help select the desired HUC-8 for analysis. The first dropdown menu, labeled **Show HUC-8s in HUC-4** is used to select the HUC-4 encompassing the study area (i.e., #1 in Figure 3). Once a HUC-4 watershed is selected, the map will zoom into the HUC-4 watershed and display the HUC-8s subwatersheds which fall within in the selected HUC-4 (Figure 4). The +/- buttons are used to zoom in and zoom out within a specific HUC-4. The user can then select a HUC-8 from the second dropdown menu labeled **Select HUC-8 for modeling** (i.e., #2 in Figure 3). Note, the map will only display HUC-8 shapefiles which have corresponding model data to display on subsequent tabs. If there is no corresponding model data, the HUC-8 will not show up in the HUC-8 dropdown menu. Conversely, some HUC-8s are not mapped because the delineation of the watershed boundary is missing from the NHDplus shapefile, however associated modeled streamflow data is available through the dropdown selection. After the HUC-8 of interest has been selected the user can click the **Go to plot** (i.e., #3 in Figure 3) button to analyze modeled streamflow data. Upon pressing the button, the tool will display the ***Model Streamflow Explorer*** tab.

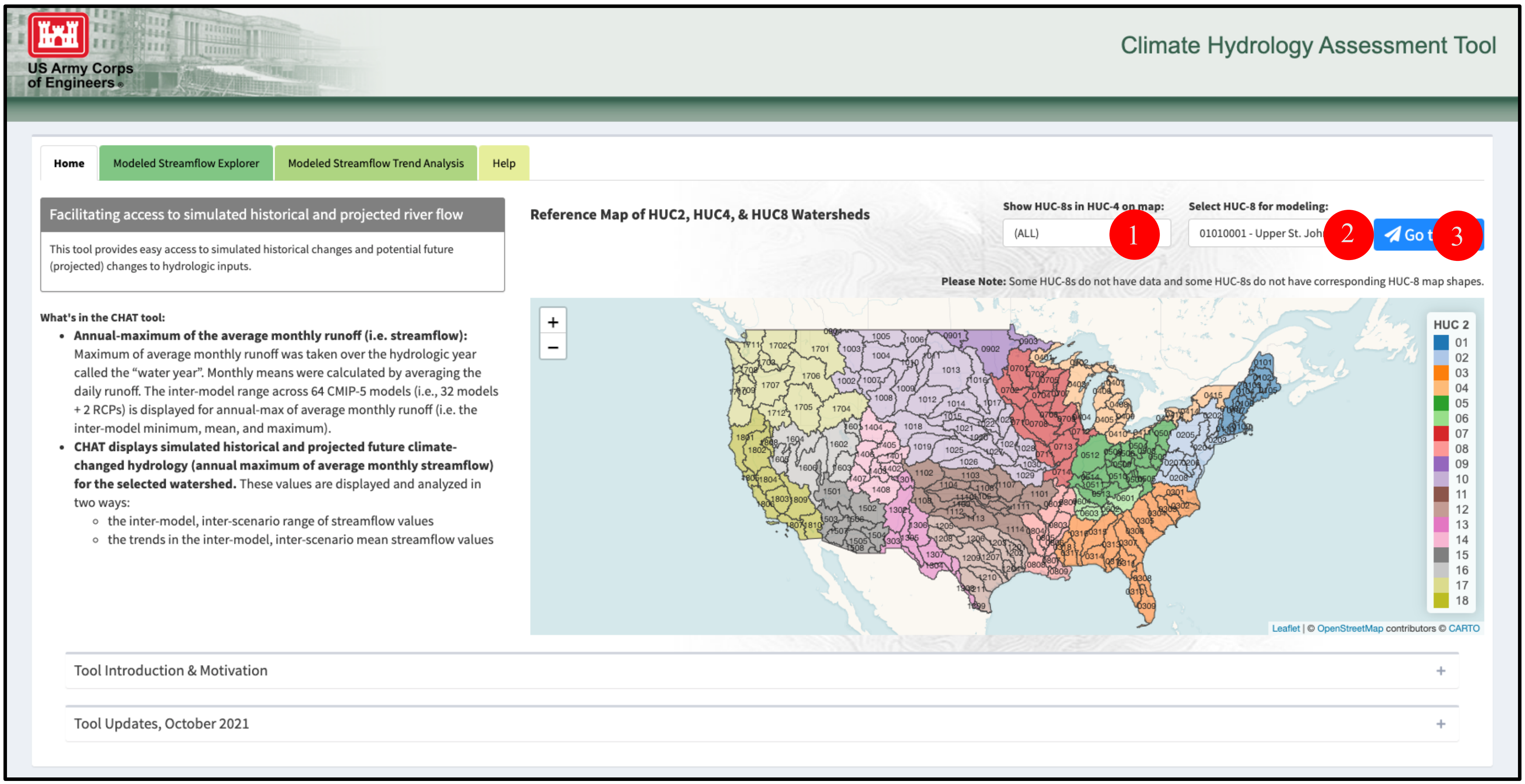


Figure 3: Home tab

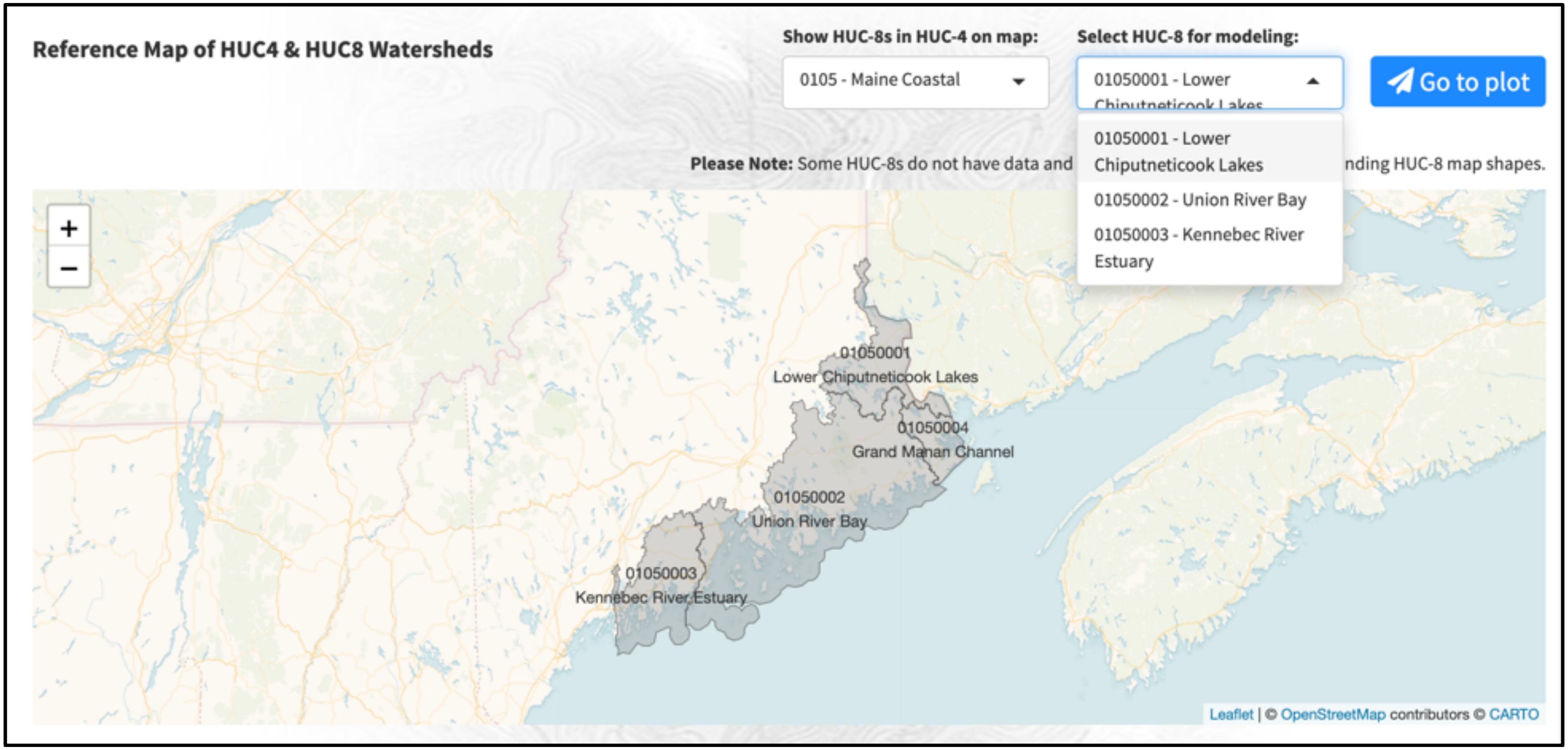


Figure 4: HUC-8 conditional dropdown list

3.2. Modeled Streamflow Explorer

To the right of the ***Home*** tab is the ***Modeled Streamflow Explorer*** tab. The banner at the top of the page displays the name of the HUC-8 associated with the data currently being displayed. The modeled annual maximum of average monthly streamflow per HUC-8 is displayed in the graph as shown in

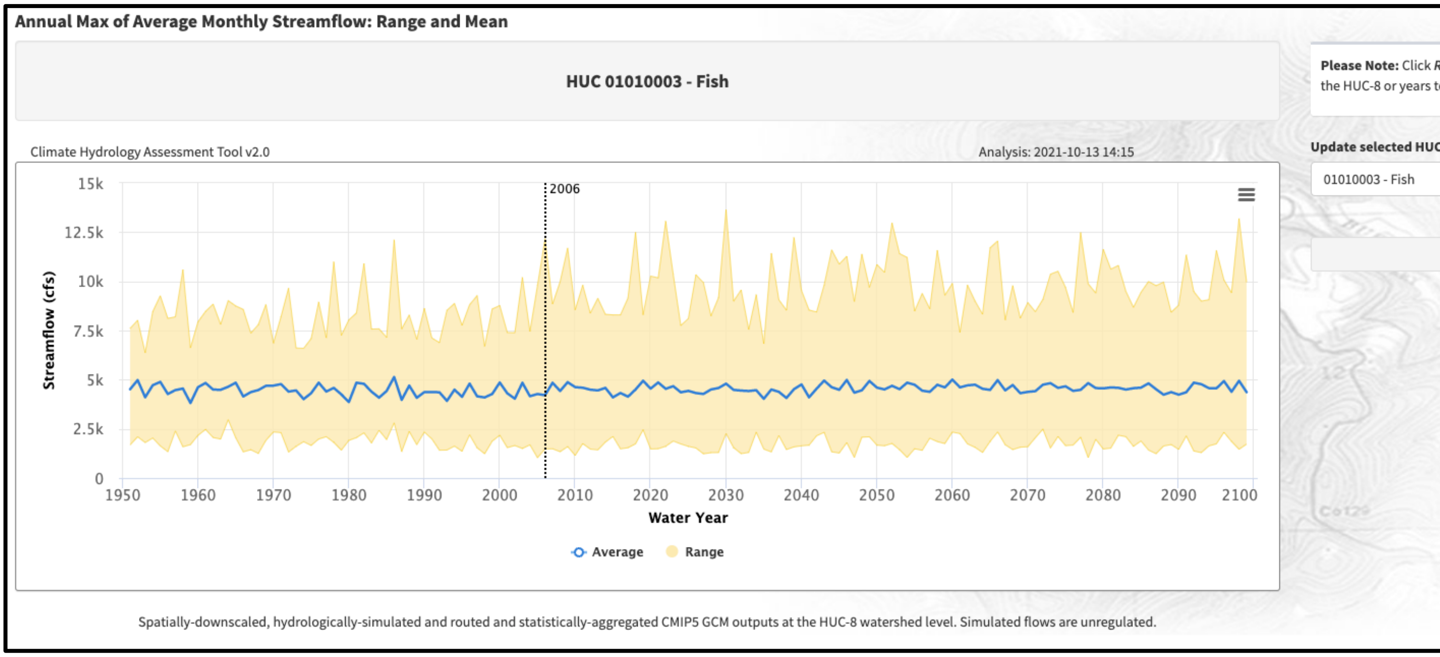


Figure 5. The resulting data is plotted in the subsequent, ***Modeled Streamflow Trend Analysis*** tab

3.2.1. Overview

The purpose of the ***Modeled Streamflow Explorer*** tab is to allow the user to visualize the average and range of output from the 64 trajectories of climate changed hydrology produced by using the GCM outputs and the VIC model outputs for the stream segment associated with the selected HUC-8 (i.e., #1 in

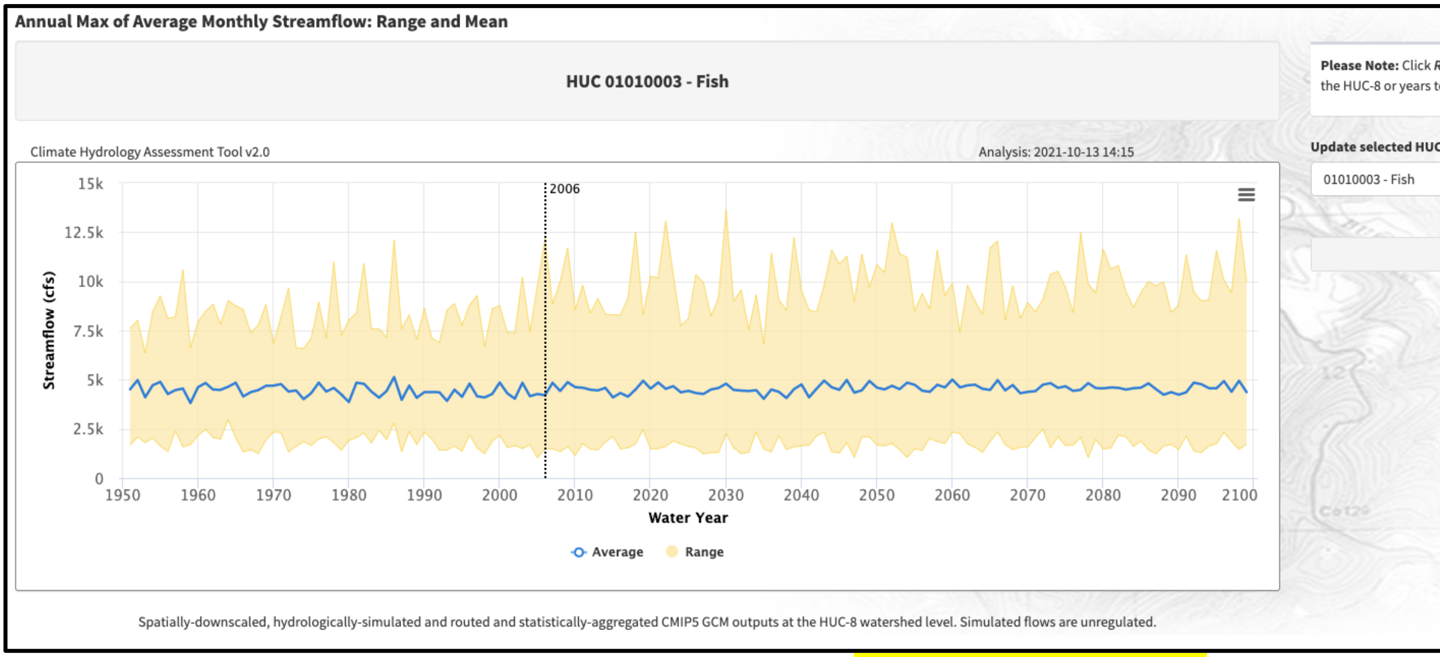


Figure 5). Values in this graph are calculated as documented in Section **Error! Reference source not found.**. By providing a visualization of the spread in model outputs, the user can conceptualize some of the uncertainty associated with the projected, climate changed streamflows. The range seen in

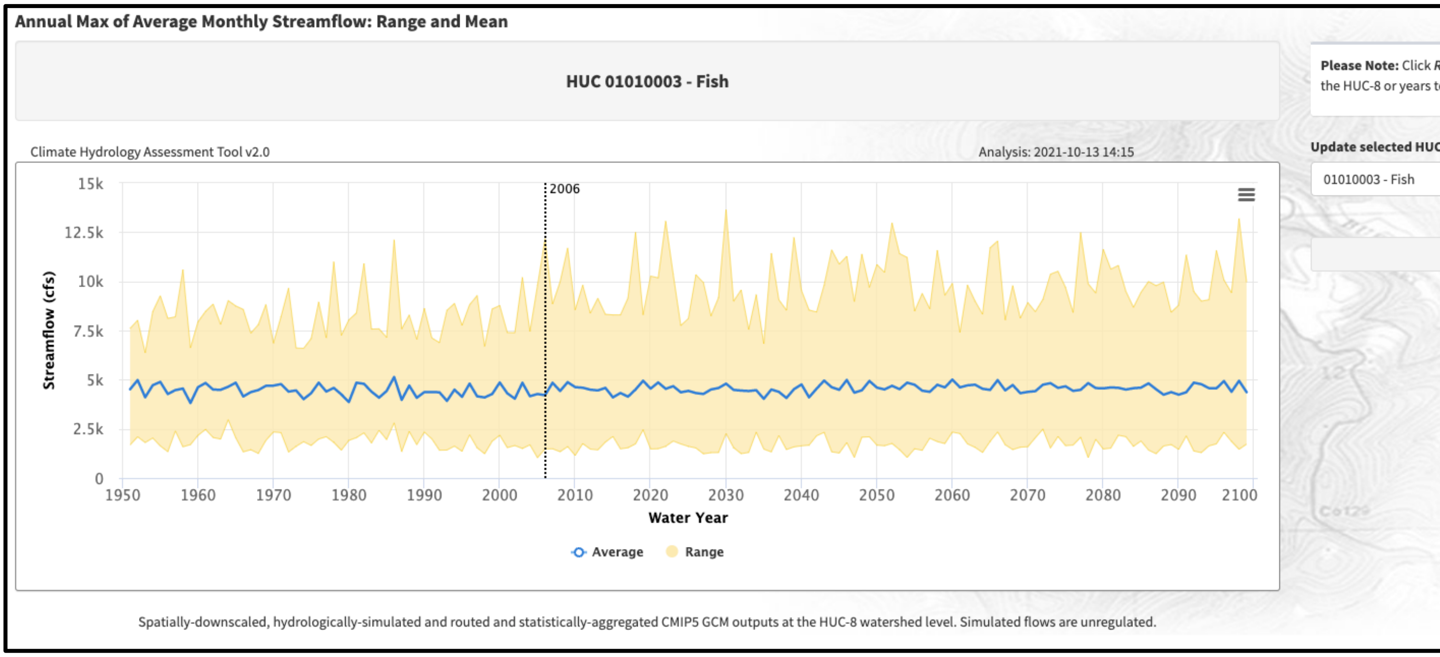


Figure 5 is in part due to the array of assumptions inherent to the selected GCMs, GCM boundary conditions, RCPs, LOCA downscaling method and VIC model.

3.2.2. Interacting with the Modeled Streamflow Explorer tab

Users can toggle to a different HUC-8 via the pull-down list in the upper-right corner of the tab (i.e., #2 in

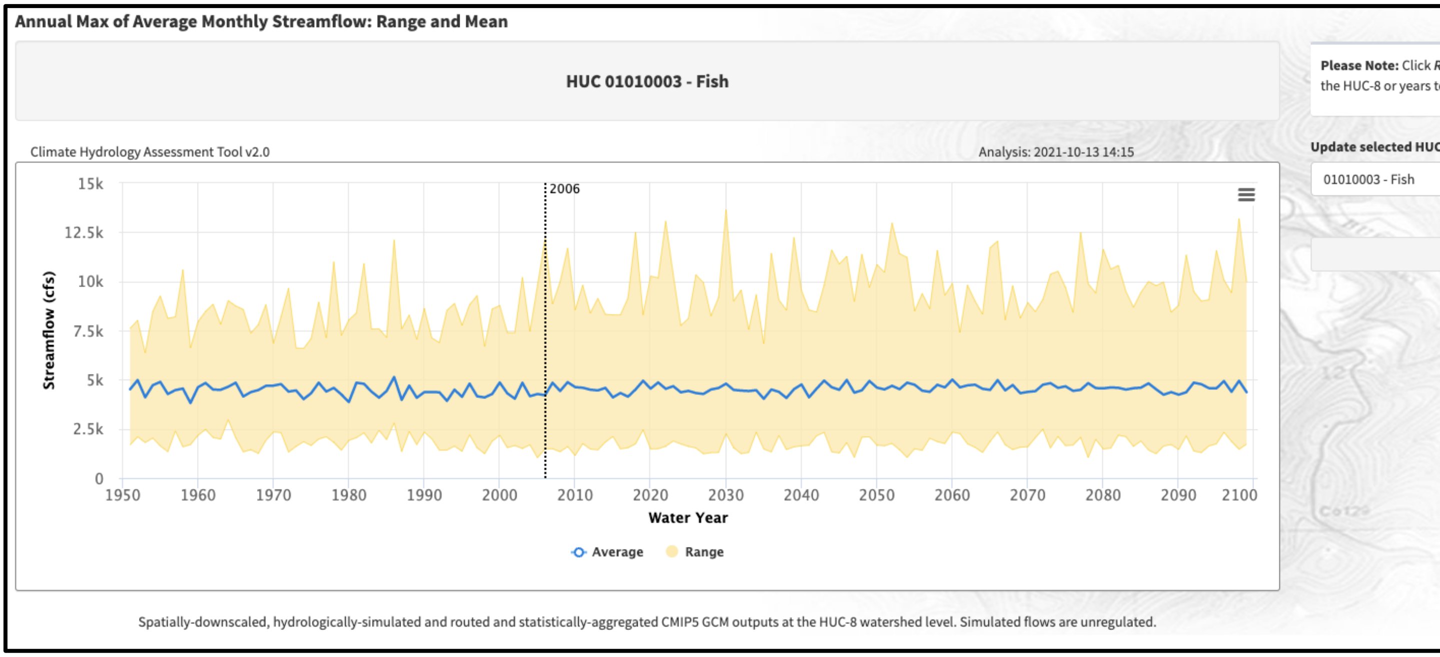
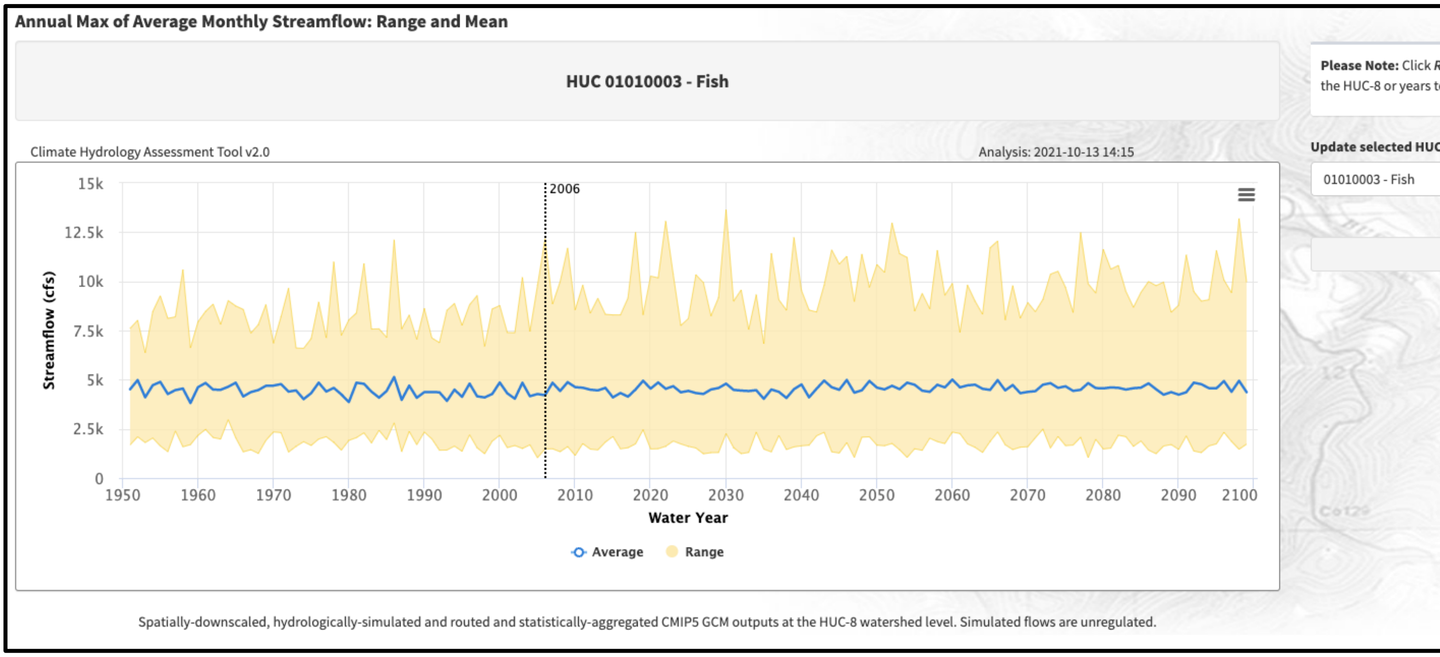


Figure 5). Upon changing the HUC-8 selection, the user must press the **Reload Plot** button to refresh the results. Users can download the graphic in their preferred file format including, PNG, JPEG, PDF, and SVG (i.e., #3 in


Annual Max of Average Monthly Streamflow: Range and Mean
HUC 01010003 - Fish
Climate Hydrology Assessment Tool v2.0
Analysis: 2021-10-13 14:15
Streamflow (cfs)
Water Year
2006
Average
Range
Spatially-downscaled, hydrologically-simulated and routed and statistically-aggregated CMIP5 GCM outputs at the HUC-8 watershed level. Simulated flows are unregulated.
Update selected HUC
01010003 - Fish
Figure 5).

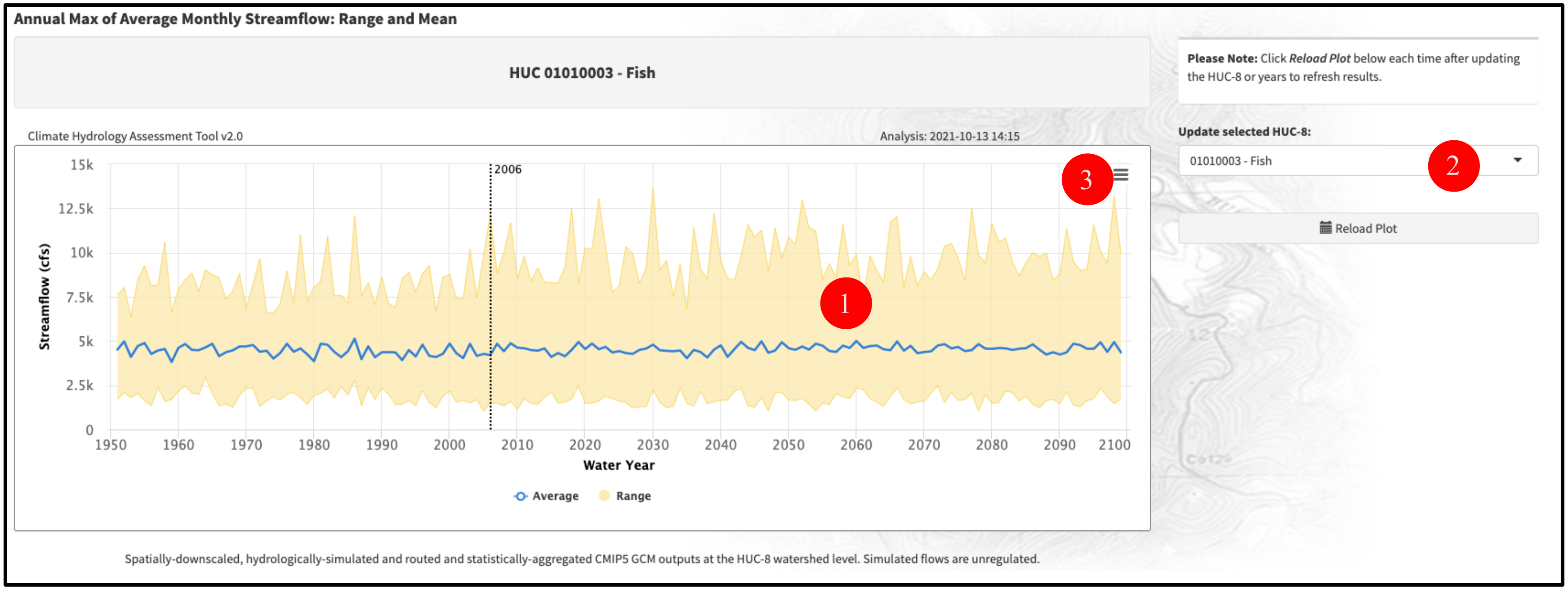


Figure 5: Model Streamflow Explorer tab

3.3. Modeled Streamflow Trend Analysis Explorer

This section shows a trendline for simulated historical data (i.e., water years 1951-2005) and projected future data (i.e., 2006-2099) and presents the results of several statistical tests for monotonic trends in the data displayed.

3.3.1. Overview

In this tab, linear regression models are separately fitted to simulated historic and projected future streamflows. Model slope, intercept, adjusted R-square, and three tests for monotonic trends are calculated for each of the two subsets of data (i.e., water years 1951-2005 and water years 2006-2099). The trends can be directly compared as a proxy for future climate impacts. Please note, the trendlines for simulated historical values and projected future values will not be continuous because the trends are calculated separately and may have different magnitudes.

3.3.2. Interacting with Modeled Streamflow Trend Analysis tab

Similar to the ***Modeled Streamflow Explorer*** tab, users can toggle to a different HUC-8 via the pull-down list in the upper-right corner of the ***Modeled Streamflow Trend Analysis*** tab (i.e., #2 in Figure 5). If the user selects a different HUC-8, the **Reload Plot** button must be used to refresh the results. The different components of the tab displayed in Figure 6 are described below.

1. Mean of 64 Annual Maximum Average Monthly Traces of Simulated Historical streamflows for water years 1951-2005 (i.e., denoted by the solid light blue line).
2. Trendline for historic period (water years 1951-2005) produced using Linear Regression (i.e., denoted by the dashed dark blue line).
3. Mean of 64 Annual Maximum Average Monthly Traces of Simulated future (projected) streamflows for water years 2006-2099 (i.e., denoted by the solid gray line).
4. Trendline for future (projected) period (water years 2006-2099) produced using Linear Regression (i.e., denoted by the black line).
5. Trendline statistics defined using simple linear regression for historic simulation (water years 1951-2005) and future (projected) periods (water years 2006-2099) (i.e., trendline equation, adjusted R^2 and t-test p-value).
6. Statistical significance tests for trends in historical simulated and projected future periods are shown in an expandable box below trendline results.
7. Users can download the graphic in their preferred file format including: PNG, JPEG, PDF, and SVG.

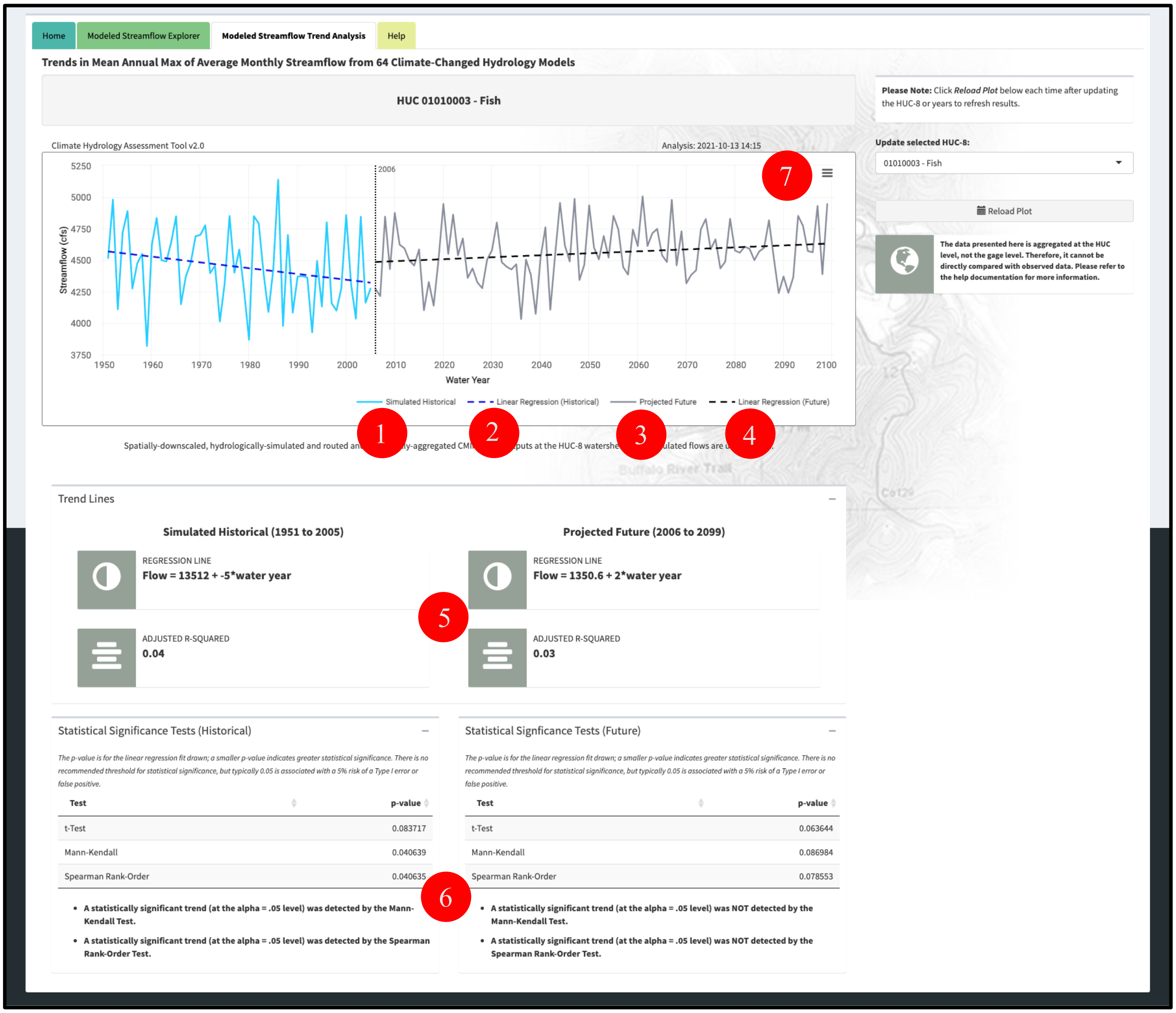


Figure 6: Modeled Streamflow Trend Analysis Explorer tab

4. *Applications to Inland Hydrology*

Changes in the high streamflow regime may have significant impacts on multiple USACE businesslines including ecosystem restoration, recreation, navigation, flood control, emergency management, water supply, and hydropower operations. While the projected streamflow data are subject to inherent uncertainties and cannot be applied to modify numerical results, CHAT tool output can be used to aid in the decision-making process. Outputs from the CHAT tool can be applied to help characterize the residual risk to a given project or operating plan due to climate change. The CHAT tool enables the user to compare the directionality and significance of trends in simulated historic datasets and projected, future streamflows generated using the same meteorologic and hydrologic modeling platforms and downscaling techniques. Differences between the simulated historical trend and projected trend metrics can be used to provide insight into foreseeable changes in the high streamflow regime due to climate change and how this might impact future conditions (i.e., with and without project).

By incorporating information related to future climate changed conditions into decision making and risk assessments, practitioners can support the need for the development and application of sustainable water management strategies and both structural and non-structural climate change adaptation solutions. The projected streamflow data can be used, alongside other resources to bolster the argument for adding resilience into projects and management plans to address projected changes in streamflow for a given HUC-8 watershed.

Practitioners can use the three metrics: 1) slope, 2) adjusted R-squared, and 3) trend significance to compare the simulated historical and projected trends as part of a assessment of the future without project conditions. Differences between the simulated historical trend and projected trend metrics can be used to gain insight into changes in future streamflow due to climate change. Potential results and follow up actions are listed below:

Table 2: Suggested Courses of Actions for Trend Significance Values

Simulated, Historical	**Projected, Future**	**Example: Suggested Interpretation**
p-value (5% significance level)		
Significant	Significant	If the directionality of the trends in historical, simulation results versus projected, future streamflows is different, it reasonable to conclude that climate change may cause a shift in future, high streamflow conditions in the basin relative to conditions observed in the past. If the directionality of the trends is the same, it may be that changes in streamflow due to climate change are already materializing in the region and can be anticipated to persist and potentially accelerate into the future.
Significant	Non-significant	Because no statistically significant trends are detected in projected, future streamflows no conclusions about projected, future climate change impacts can be made based on CHAT ouptut. The trend in historic streamflows should be discussed, but its implications with respect to climate change area uncertain.
Non-significant	Significant	With the information available, there is not enough evidence to suggest a trend in the simulated, historical data. The statistically significant change in projected, future

		streamflows suggests changes in the future without project condition due to climate change.
Non-significant	Non-significant	If there is no statistically significant trend detected in either the historic or projected streamflows no conclusions related to projected, future climate change impacts can be made based on CHAT output.

For more information on the calculations to derive the above metrics, please refer to Section 2.1.5.

5. Change log

- Updated tool to R-Shiny
- Use models and scenarios from Coupled Model Intercomparison Project Phase 5 (CMIP-5)
- Updated spatial resolution from HUC-4 to HUC-8 for model projected streamflow
- Model projections include runoff outputs from hydrological model driven by Representative Concentration Pathways (RCPs) 4.5 and 8.5.
- Projected futures for ***Modeled Streamflow Trend Analysis*** tab now start at the year 2006 rather than 2000.
- Removed ***Site Selector*** tab
- Removed ***Observed Streamflow*** tab. Updated ***Trend Analysis*** tab in Nonstationarity Detection Tool (NSD) with Infoboxes containing summary information from ***Observed Streamflow*** tab.
- Moved Reference HUC-8 map to ***Home*** tab
- Resolved display names issues for HUC-4s on HUC-8 map.
- Added help text to remind users to refresh graphs after changing HUCs on ***Modeled Streamflow Explorer*** and ***Modeled Streamflow Trend Analysis*** tabs.
- Removed reload animation after choosing new HUC. Information on each page will refresh only after the action button is clicked.
- Fixed legend on ***Modeled Streamflow Trend Analysis*** tab to clearly distinguish line types.
- Added conditional message for HUCs with missing data.
- Fixed sync issues for graphics on ***Modeled Streamflow Explorer*** and ***Modeled Streamflow Trend Analysis*** tab
- Updated color scheme on all tabs to be 508 compliant
- Removed “Change Displayed Date Range of Modeled Data” from ***Modeled Streamflow Explorer tab***
- Removed “Select Year Dividing ‘Earlier’ and ‘Later’ Periods” from ***Modeled Streamflow Trend Analysis tab***
- Added plotline at water year 2006 to identify start year of projections for ***Modeled Streamflow Explorer*** and ***Modeled Streamflow Trend Analysis*** tabs
- Added help text to remind users not to compare information in tool with observed streamflow.
- Changed tab name from “Modeled Projected Streamflow” to “Modeled Streamflow Explorer”
- Changed tab name form “Modeled Streamflow Trend” to “Modeled Streamflow Trend Analysis”
- Removed “Qualitative” and “hindcast” from UI.
- Removed t-test p-value Infobox from ***Modeled Streamflow Trend Analysis*** tab
- Changed default setting for tables displaying significance test values so information will always display in ***Modeled Streamflow Trend Analysis*** tab.

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